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Modern Metaphysics

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Abstract

Metaphysics is the science of being and asks the question "What really exists?" The answer to this question has been sought for by mankind since the beginning of recorded time. In the past 2500 years there have been many answers to this question and these answers dominate our view of how physics is done. Examples of questions which were originally metaphysical are the shape of the earth, the motion of the earth, the existence of atoms, the relativity of space and time, the uncertainty principle, the renormalization of field theory and the existence of quarks and strings. I will explore our changing conception of what constitutes reality by examining the views of Aristotle, Ptolemy, St. Thomas Aquinas, Copernicus, Galileo, Bacon, Descartes, Newton, Leibnitz, Compte, Einstein, Bohr, Feynman, Schwinger, Yang, Gell-Mann, Wilson and Witten.

1. Introduction

In recent years Physics has come under attack from politicians and from many in the general public. The funding for the Superconducting Super Collider was terminated, job prospects are drying up, and nuclear physics has become so unpopular as a result of the nuclear power debate that the very word nuclear has been dropped from Nuclear Magnetic Resonance in order that the general public will accept Magnetic Resonance Imaging as a medical tool.

This hostility to physics is not a new phenomena and has very deep and ancient roots. For example at the end of Roman Empire St. Augustine wrote [1]

Th good Christian should beware of mathematicians, and all those who make empty prophecies. The danger already exits that the mathematicians have made a covenant with the devil to darken the spirit and to confine man in the bonds of Hell.

Somewhat more recently, in 1511 during the Renaissance, Erasmus wrote in "In Praise of Folly" [2]

Near these march the scientists, reveranced for their beards and the fur on their gowns, who teach that they alone are wise while the rest of mortal men flit about as shadows. How pleasantly they dote, indeed, while they construct their numberless worlds, and measure the sun, moon, stars and spheres as with thumb and line. They assign causes for lightening, winds, eclipses and other inexplicable things, never hesitating a whit, as it they were privy to the secrets of nature, artificer of things, or as if they visited us fresh from the council of the gods. Yet all the while nature is laughing grandly at them and their conjectures. For

to prove that they have good intelligence of nothing, this is a sufficient argument: they can never explain why they disagree with each other on every subject. Thus knowing nothing in general, they profess to know all things in particular; though they are ignorant even of themselves, and on occasion do not see the ditch or the stone lying across their path. because many of them are blear-eyed or absent minded; yet they proclaim that they perceive ideas, universals, forms without matter, primary substances, quiddities and ecceities–things so tenuous, I fear, that Lynceus himself could not see them. When they especially disdain the vulgar crowd is when they bring out their triangle, quadrangles, circles and mathematical pictures of the sort, lay one upon the other, intertwine them into a maze, then deploy some letters as if in line of battle, and presently do it over in reverse order–and all to involve the uninitiated in darkness. Their fraternity does not lack those who predict future events by consulting the stars, and promise wonders even more magical; and these lucky scientists find people to believe them.

I do not agree with the conclusions of St. Augustine, Erasmus, and those who would contract the support for research in physics. On the contrary I think that physics and physics education is of great importance for the general public. In particular I think that all students can profit greatly from learning the way that physicists think about the world.

Nevertheless the criticism of Erasmus is still very mush to the point even though it is almost 500 years old. Physicists still have the habit of speaking in a specialized language and of relying heavily on mathematical symbols and arguments. This drastically limits the audience to which we can communicate our ideas.

I would like to think that this state of affairs can be improved upon and thus my first goal for this paper is an attempt to see if I can convey the essence and importance of physical thought down through the ages from Aristotle to Witten in a form which is accessible to people with no laboratory experience and which does not use any mathematics. In other words I will attempt to explain physics from a humanist perspective.

My second goal for this paper is more specialized. I want to give an overview of the evolution of theoretical physics in the last 50 years from a discipline which sought guidance from experiments to one which gives guidance to mathematics. This change is dramatically illustrated by comparing 1957 with 1990. In 1957 Lee and Yang won the Noble prize in physics by using theoretical methods to explain a puzzle concerning particle decays which had been found by high energy physics experiments. In 1990 Witten won the Fields Medal in mathematics by using methods of physics to solve theoretical problems posed by mathematicians. In both cases the methods used are those of quantum field theory but

the ends to which those methods are employed are drastically different. Moreover these two cases are not isolated instances but are representative of a change in attitude and direction which, in my opinion, can be rather precisely dated to have begun in 1964 with the paper by Gell-Mann which introduces the concept of quarks. It is this historic change of direction of theoretical physics which I had originally planned to discuss in this paper.

However in preparing this paper I have became aware that in any attempt to generalize about the direction of research in physics I tread on very dangerous ground and that there is no way in which I can expect that most of my colleagues are going to agree with everything I want to say. Consequently, in order not to run into semantic difficulties at the very beginning I have chosen instead to write on what I choose to call metaphysics instead of theoretical physics. In this way if I offend anyone it will, I hope, be limited to members of philosophy departments.

2. Rules for Learning

The first lesson from philosophy that needs to be understood is that terrible misunderstandings arise from the unavoidable fact that communication requires language and in order for two people to communicate they must have the same understanding of the words they use. Unhappily this means that if I am trying to communicate to you an idea which I have but which you do not then the communication cannot possibly succeed because we cannot possibly have the same language in common. Thus it is philosophically impossible for me to teach you anything new at all. This phenomena that teaching is impossible is encountered by professors every day they teach a class.

However, the converse is indeed possible. That is even though I cannot teach I can learn. This will mean that I will be interpreting and giving my meaning to the words of others. You can, if you will, say that I am making a translation from the language of others into my own language. Sometimes this is translation in a literal sense as when the original article is written in French, German, Latin or Greek. Sometimes it is an interpretation from mathematical to physical language and often it is the translation of ideas. But in all cases the learning I have in mind is something which occurs in the mind of the learner and not in the mind of the teacher.

In order to effectively learn anything it is most helpful for the learner to have a method. And thus I want to begin by outlining some rules for learning.

First a rule of my own invention:

1) **Always look for what is correct in an author.**

Never adopt the attitude that if you can find one thing wrong in someone's writing or thinking that everything else they write or say is to be disregarded. If you do this you will soon discover that you cannot read anything because there is no book or writer that does not contain something which you will call an error. Instead you must look for what is true and useful. The result is then that you must judge a writer by his best and ignore his errors in assessing his reputation.

Let me give an example:

Ptolemy was the greatest astronomer of the ancient world. His book "The Almagest" [3] written in 150 AD is a scientific masterpiece. He proves the world is round even though the direct experimental proof of Magellan was completed only in 1522. Ptolemy was able to describe the midnight sun from theoretical reasons alone even though in 150 AD no one who has left a written record had ever been north of the arctic circle. Ptolemy understood the precession of the equinoxes and had a wonderful method of calculating eclipses and the observed motion of the planets which gave a very precise fit to the data. The man must be regarded as a genius.

And yet the typical assessment of Ptolemy is that he was a fool because he thought that the sun moved and the earth stood still. My rule says that Ptolemy must be judged for the many things he got right and not for the very few things he got wrong.

The second rule is from Descartes in his famous *Discourse on Method* [4] written in 1637.

2) **Begin by doubting everything.**

This is very easy to say but very hard to put into practice. In particular you must never accept someone's belief or idea on the basis of their authority, status, or position in the field. This is naturally bound to get you into a lot of trouble. It even got Descartes into a lot of trouble and he lived much of his life in exile from his native France because of it.

The remaining rules are those given by Francis Bacon in his book *Novum Organum* [5] written in 1620 and are called by him the four idols:

3) **Idols of the tribe:**

These are errors of learning which are inescapably common to all mankind. They arise because *"It is the case that all our perceptions, both of our sense and of our minds, are reflections of man, not of the universe, and that human understanding is like an uneven*

mirror that cannot reflect truly the rays from objects, but distorts and corrupts the nature of things by mingling its own nature with it."

For example:

"The human understanding on account of its own nature readily supposes a greater order and uniformity in things than it finds. And though there are many things in nature which are unique and quite unlike anything else, the understanding devises parallels, correspondences and relations which are not there ⋯

The human understanding, since it has adopted opinions, either because they were already accepted and believed, or because it likes them, draws everything else to support and agree with them. And though it may meet a greater number and weight of contrary instances, it will, with great an harmful prejudice, ignore or condemn or exclude them by introducing some distinction, in order that the authority of those earlier assumptions may remain intact and unharmed ⋯

The human understanding is most moved by things that strike and enter the mind together and suddenly... .It then imagines that everything else behaves in the same way as those few things with which it has become engaged ⋯

The human understanding ... is infused by desire and emotion, which give rise to 'wishful science' "

And finally *"by far the greatest impediment and aberration of the human understanding arises from the dullness and inadequacy of the senses."*

4) **Idols of the cave:**

These are errors in learning which are characteristic of individuals personal ego and education.

In particular:

"Men become attached to particular sciences and contemplations because they think themselves their authors and inventors, or because they have done much work on them and have become habituated to them."

5) **Idols of the forum:**

These are errors in learning which are caused by the unavoidable use of words and the "alliance of words and names." They are of two kinds. *"Either they are names of things that do not exist (for just as there are things without names because they have never been seen, so also there are names without things, as a result of fanciful suppositions); or they are names of objects which to exist but are muddled and vague."*

6) **Idols of the theater:**

These are errors of learning which are not innate to knowledge itself but *"are imposed and received entirely from the fictitious tales in theories, and from wrong-headed laws of demonstration."*

For example:

"The school of rational philosophers seizes from experience a variety of common instances without properly checking them, or thoroughly examining and weighing them, and leaves the rest to cogitation and agitation of wit."

On the other hand there is a *"class of philosophers who, after toiling with great care and precision over a few experiments, have presumed to devise and produce philosophies from them, twisting everything else in extraordinary ways to fit in with them."*

I rather suspect that in these quotes from 1620 it is possible to recognize traits that may be seen in your colleagues and which you may have had to fight against in your own thinking and research.

I will attempt to use these 6 rules as precepts for what follows in this lecture.

3. Natural Science, Mathematics and Metaphysics:Aristotle to Aquinas

It is a very common literary device to use when writing a paper to start by referring to something which is "recent". Thus Voltaire in the beginning of the 18th century writes about the "recent " work of Newton; papers on particle physics in the 60's and 70's would talk about the "recent"work of Gell-Mann; and today many papers can be found which start with the formula "Recently Witten..."

But I plan to discuss metaphysics and the very word "metaphysics" has gone out of use and out of fashion with physicists hundreds of years ago. Indeed its use was ridiculed and it was in effect forced out of physics by a centuries long campaign of abuse. Therefore I cannot possibly start my discussion by citing "recent authors" and consequently I will of necessity adopt the opposite strategy of beginning my presentation with the first author who considered the topic instead of the most recent. I thus begin by quoting from the book *Metaphysics* by Aristotle [6] written in the fourth century BC.

There are three kinds of theoretical philosophy; mathematics, natural science and metaphysics.

The meanings the words theoretical, mathematics, natural, and metaphysics have been discussed by some of the most profound philosophers of ancient and medieval times. I will here follow the unsurpassed treatment given by St.Thomas Aquinas in *Expositio*

super Lebrum Boethii de Trinitate [7] written during 1255–1259 as an explanation of the book *de Trinitate* written by the Roman philosopher Boethius in the sixth century.

St. Thomas begins by quoting Boethius whom I summarize as follows:

"Come then, let us enter into each matter, discussing it so it can be grasped and understood, for it seems well said that educated people try for such certainty as the matter itself allows.

For theoretical science divides into three—

1) Natural science (physics) which deals with observed matter which undergoes change. The ideas studied by physics are not abstracted from observed matter and embody all the changes which matter is subject to.

2) Mathematics which conceives bodily forms apart from matter and thus apart from change though the ideas themselves do exist in matter and so cannot be separated from matter and change.

3) Metaphysics which is changeless, abstract and separated from observed matter.

In natural science we make use of reason, in mathematics we make use of discipline and in metaphysics we use the intellect which does not rely on imagination but rather scrutinizes existence itself from which all existence exists."

First we should understand what St.Thomas means by theoretical:

"*Speculative or theoretical, as distinct from operative or practical, understanding is characterized by attention to truth for its own sake, rather than as the means to some other activity... .The subject matter of practical sciences has to be things we can make or do... .The subject matter of theoretical sciences, on the other hand, has to be things not made by us, which we cannot be seeking to know for activities sake."* Thus St. Thomas makes a distinction between what we now call pure physics which he calls theoretical and applied physics which he calls a practical art. Moreover the branches of philosophy of ethics, aesthetics and politics are also regarded by St.Thomas as practical and not as theoretical branches of knowledge.

Next we need to understand his conception of physics (or natural science). The role of physics is to comprehend what can be observed by sensory perception and what we can make images of in our mind (imagination). Physics studies observed matter which has bulk, quantity and can be observed and measured and this matter is in general not static but is undergoing change. We study matter by using the processes of reason. *"Natural science starts from what is more knowable to us and less knowable in its own nature, using*

proofs from symptoms and effects." We derive knowledge of one thing from knowledge of something external to it—knowledge of effects, for example, from knowledge of their cause.

This definition agrees very well with that of the present day.

Moreover St.Thomas's conception of mathematics is exactly that of the present day. From observed matter Thomas abstracts the notion of quantity. *"Quantity, therefore does not depend for its definition on material–as –perceptible but only on material–as– thinkable; namely, substance without its material properties, which is something only thought can comprehend, and to which our senses cannot penetrate. Mathematics is the science of objects abstracted in this way, and considers only quantity in things and whatever accompanies quantity; shapes and the like. ⋯ In the mathematical science we argue from definitions of things, proving conclusions by appeal to formal principles, never deriving truths about something by appeal to something external to it but by appeal to its own definition."* Quoting Ptolemy he says *"Only mathematics, if you examine matters closely, builds up in its students sure and stable beliefs by means of irrefutable proofs."* This is what he means by the discipline which he says is characteristic of mathematics.

It remains to discuss what St. Thomas means by metaphysics.

There are two concepts which are crucial in the understanding of the metaphysics of Aquinas: 1) incommensurable length scales and 2) immaterial substances.

By incommensurable length scales Aquinas means that the ratio of the length scale of metaphysical objects and phenomena to the length scale of observed physical material phenomena is strictly infinite (or zero depending on how you look at it).

By immaterial substance Aquinas means that the fundamental objects on this infinite metaphysical length scale are not in any direct manner connected with observed matter on the physical length scale. Indeed, Aquinas stresses that it is quite inappropriate to even attempt to use the words and properties which we use to describe observed matter to describe an immaterial metaphysical substance.

The metaphysics of St.Thomas is the statement that the immaterial objects of the infinite length scale constitute the unchanging basis of physical reality and that all observed material phenomena are to be derived from them. The process of derivation is through mathematics much in the sense that mathematics allows us to discuss the concept of a limit and here again Aquinas is very clear that the properties of a limit do not have to be the same as the objects through which the limit is taken.

St.Thomas thus gives a very concrete explanation to his students of what he interprets Boethius to mean by saying that metaphysics is changeless, abstract and separated from matter.

This metaphysics is remarkably sophisticated, and for this remarkable sophistication Aquinas was greatly rewarded, He was granted tenure in this world and when he passed on to the next world the Catholic church made him a saint, an honor no scientist since his time has attained.

But the concepts of infinite ratios of length scales and immaterial substances which are not the same as observed matter were very hard to swallow. Moreover, this metaphysics is only what we would call today a kinematics and does not contain any dynamical principle. Consequently, although it provides a quite plausible framework in which to discuss reality it does not provide any tools to allow the computations of any actual properties or effects, and in time this metaphysics was slowly abandoned by the scientific community. Indeed it was more than abandoned it was ridiculed and castigated and Aquinas himself was subjected to a remarkable amount of *ad hominum* abuse and the development of scientific thought went in an entirely new direction.

4. Galileo's revolution of 1610

The next great advance in science came in the mid 16th century when Copernicus boldly argued on theoretical grounds that the earth was not the center of the universe but that instead the earth moved around the sun. But even this, epoch making as it was, takes second place to the totally revolutionary publication by Galileo on March 12, 1610 of the paper *Siderius Nuncius* [8].

It is absolutely impossible to overstate the importance of this paper of Galileo. In it he announces three things which were totally unanticipated and epoch making:

1. The invention of the telescope;

2. The observation of mountains on the moon;

3. The discovery of four moons of Jupiter;

Even after the passage of 386 years the excitement of Galileo is infectious:

"In this short treatise I propose great things for inspection and contemplation by every explorer of Nature. Great, I say, because of the excellence of the things themselves, because of their newness, unheard of throughout the ages, and also because of the instrument with the benefit of which they make themselves manifest to our sight.

Certainly it is a great thing to add to the countless multitude of fixed stars visible hitherto by natural means and expose to our eyes innumerable others never seen before, which exceed tenfold the number of old and known ones.

It is most beautiful and pleasing to the eye to look upon the lunar body, distant from us about sixty terrestrial diameters, from so near as if it were distant by only two of those measures, so that the diameter of the same moon appears as if it were thirty times... larger than when observes only with the naked eye. Anyone will then understand with the certainty of the senses that the moon is by no means endowed with a smooth and polished surface, but is rough and uneven and, just as the face of the Earth itself, crowded everywhere with vast promontories, deep chasms, and convolutions.

But what greatly exceeds all admiration, and what especially impelled us to give notice to all astronomers and philosophers, is this, that we have discovered four wandering stars, known or observed by no one before us... All these things were discovered and observed a few days ago by means of a glass contrived by me after I had been inspired by divine grace."

Galileo's revolution has been so complete that the statement I gave of it does not even sound revolutionary. What he did was to built an experimental apparatus and use it to make an observation which had not been possible before that apparatus was built. We do not think today that this is strange. What is revolutionary in Galileo's work is the **this is the first time observations with instruments had ever been done.**

The metaphysical consequences of this paper were profound and immediate. For all of previous history the words *sensory perception* had meant **unaided** sensory perception. The immediate metaphysical question to answer was this: **Are observations made with instruments to be considered as being real?** In other words, were the moons of Jupiter really out there in the heavens or were they inside the telescope of Galileo. However, unlike all previous metaphysical questions this one was answered within a year. The universal answer was that if the observations with instruments could be repeated by others then the phenomena had just as much status to the title of reality as any observation which did not involve instruments.

With the invention of the telescope science underwent a permanent change. Suddenly improvements in technology meant that logic and deductive reasoning were not the only way to learn about nature. Anyone who could build a better lens or microscope could go and point it at something and make a new discovery without paying any attention to the theory at all. And thus the metaphysics and definition of reality of Aquinas was abandoned in a mad rush. With the invention of the telescope the dominance of theoretical

over experimental methods which had existed for almost 2000 years was overthrown. Why should anyone worry about the true definition of reality and being when there were new planets and new biology to discover?

5. The experimental metaphysics of Bacon

Such a profound revolution in technology demanded an equally profound revolution in the metaphysical basis of science. This was provided within 10 years by Bacon in the same book which contained the four idols we talked about before. In *Novum Organum* Bacon sets forth a scientific method which is diametrically opposed to the metaphysical conception of reality of Aquinas. Bacon's method has been so universally accepted that for generations it has been called *the* scientific method. It is taught in our elementary and secondary schools as absolute truth. It has caused the very definition of physics to go from a theoretical science to an experimental science.

I quote again from *Novum Organum* [9]

"Now the directions for the interpretation of Nature are of two separate kinds: the first for eliciting or devising axioms from experience, the second for drawing or deriving new experiments from axioms. the former again is divided three ways, that is into three provisions: that for the sense, for the memory, and for the mind or reason.

First of all, a sufficient and suitable natural and experimental history must be compiled. That is fundamental to the matter. For there must be no imagining or supposing, but simply discovering, what nature does or undergoes.

But this natural and experimental history is so various and scattered that it would confuse and distract the understanding, unless it is set out and presented in a suitable order, for which purpose table and arrangements of instances should be drawn up, and put together in such a manner and order as to enable the understanding to deal with them." Only then are we able to *"employ a legitimate and true induction, which is the very key of interpretation."*

Bacon [10] makes very explicit the relation which he thinks his method has to the incommensurable length scales of Aquinas:

"In this way we shall be led, not to the atom, which presupposes a vacuum and immutable substance (both of which are false) but to real particles such as are found. Nor again is there cause for alarm at the subtlety of the inquiry, as if it were inexplicable; on the contrary the closer the inquiry comes to simple natures, the more intelligible and clear

will everything become; the business will be transferred from the complicated to the simple, from the incommensurable to the commensurable, from the irrational to the rational, from the indefinite and doubtful to the definite and certain."

There is no place in Bacon's theory for infinite length scales and certainly there is no place for "immaterial substances." For Bacon the question of reality and being is self evident. If you can perceive it and measure it it is real. Otherwise don't talk about it. Or as Bacon puts it [11] *"there are two practical division in science; physics corresponds to the mechanical arts; metaphysics corresponds to magic."*

Bacon resoundingly places experiment above theory.

Bacon was also extremely successful with his method. In his book Bacon applies his method to the question of heat and concludes by finding that **heat is motion.** In other words, in 1620 Bacon invented the kinetic theory of gases and heat on the basis of analyzing the experimental evidence of his day. Truly an achievement of genius.

6. The gravitation, vacuum and particles of Newton

But an even greater creation of genius is the invention of the universal theory of gravitation by Newton as published in the *Principia* of 1687. I think it is fair to say that no scientist in history has so deeply impressed the general public. As proof of this I offer a description of Newton's discovery written not by a scientist but by one of the greatest of all writers of the 18th century, Voltaire [12]

"He (Newton) said to himself: 'From whatever height in our hemisphere these bodies might fall, their fall would certainly be in the progression discovered by Galileo, and the spaces traversed by them would be equal to the squares of the time taken. This force which makes heavy bodies descend is the same, with no appreciable diminution, at whatever depth one may be in the earth and on the highest mountain. Why shouldn't this force stretch right up to the moon? And if it is true that it stretches as far as that, is it not highly probable that this force keeps the moon in its orbit and determines its movement? But if the moon obeys this principle, whatever it may be, is it not also very reasonable to think that the other planets are similarly influenced.

If this force exists it must increase in inverse ratio to the squares of the distances. So it only remains to examine the distance covered by a heavy body falling to the ground from a medium height, and that covered in the same time by a body falling from the orbit

of the moon. To know this it only remains to have the measurements of the earth and the distance from the earth to the moon.'

This is how Newton reasoned. But in England at that time there existed only very erroneous measurements of our globe...As these false calculations did not agree with the conclusions Newton wanted to draw, he abandoned them. A mediocre scientist, motivated solely by vanity, would have made the measurements of the earth fit in with his system as best he could. Newton preferred to abandon his project for the time being. But since M. Picard had measured the earth accurately by tracing this meridian, which is such an honor for France, Newton took up his first ideas again and found what he wanted in the calculations of M. Picard. This is a thing that still seems admirable to me; to have discovered such a sublime truths with a quadrant and a bit of arithmetic."

But, unlike the kinetic theory of heat, whose explanation has not changed since the time of Bacon, this gravitational attraction which is an instantaneous action at a distance was and is metaphysically unsettling. And Newton knew it. To quote Voltaire again:

"Newton foresaw clearly when he had demonstrated the existence of this principle that people would revolt against its very name. In more that one place in his book he cautions the reader against gravitation itself and warns him not to confuse it with what the ancients termed occult qualities, but to be satisfied with the knowledge that there is in all bodies a central force which acts from end to end of the universe on the nearest and most distant bodies in accordance with the changeless laws of mechanics."

Indeed, Newton was right. In theoretical and metaphysical terms this action at a distance was very hard for some to swallow. One of those who would not swallow it was Leibnitz who for his entire career argued for what we now call a principle of locality. Leibnitz [13] in his paper which is in reply to the *fourth paper* of Clarke says *"It is a strange fiction to regard all matter as having gravity, and even to regard it as gravitating towards all other matter, as if every body had an equal attraction for every other body in proportion to mass and distance; and this by means of attraction properly so called, and not derived from an occult impulsion of the bodies. Whereas in truth the gravitation of sensible bodies towards the center of the earth must be produced by the movement of some fluid. And the same is true of other gravitations such as those of the planets towards the sun or towards one another. A body is never moved naturally except by another body which impels it by touching it; and after this it goes on until it is hindered by another body touching it. Any other operation on bodies is either miraculous or imaginary."*

Leibnitz thus is in explicit contradiction with Newton and condemns the hypothesis that the gravitational attraction of bodies could proceed instantaneously without a time delay. Instead he believed that forces could only act by direct contact. It is difficult to call him wrong but he had no competing theory that would make predictions of planetary motions. Consequently Leibnitz ran into the same sort of abuse which Aquinas did and at the hands of Voltaire suffered tremendous personal attacks and condemnation. His reputation survived because he was, after all, one of the inventors of the calculus and because he could compute as well as Newton. But the credit in the 18th century for the revolution in human thought caused by the invention of the science of mechanics was all given to Newton.

If action at a distance was the only metaphysical invention of Newton that would already be profound but in fact Newton had a much larger impact than even gravity would indicate and another of the key results which the 18th century credited Newton was the demonstration of the existence of the vacuum.

At the time of Newton it was hotly debated whether space was filled with continuous matter or whether there was such a thing as empty space. Descartes, for example, argued that the universe was filled with some substance, called a *plenum* and that objects such as the planets consist of vortices in this substance. In contradiction to this was the metaphysical idea of Newton that there was such a thing as empty space and that reality consisted of very tiny material particles which moved in this space. The metaphysics of Newton is diametrically opposed to Descartes (and indeed also is opposed to Bacon). The history of 18th century physics is the triumph of Newton's ideas of gravity, empty space, atomism at the expense of continuous matter and local interactions.

7. Fields and Relativity

However the metaphysics of locality and continuity had an appeal that did not die even with the enormous success of Newtonian mechanics and indeed proved to be exactly the metaphysics needed by the 19th century for the study of electromagnetism. It had been known from the beginning of the 18th century with the work of Roehmer that the velocity of light was finite and that light did not have an infinite velocity like the action at a distance of Newtonian gravity. The theoretical work of Faraday and Maxwell created for electromagnetism a metaphysical framework that threw out everything which Newton had used. Faraday and Maxwell described electromagnetism in terms of a field which is

present at every place in space. It is this field which carries radio and television signals. This field is viewed as real and interactions with the field are local in exactly the sense that Leibnitz meant by the word local.

The completion of the destruction of Newtonian metaphysics was carried out by Einstein. In the general theory of relativity Einstein not only replaced the vacuum by fields but replaces the gravitational action at a distance in the static unchanging space of Newton by a dynamic space where geometry itself changes.

But neither Faraday, nor Maxwell, nor Einstein found it necessary to eliminate the notion of a particle. Thus at the beginning of the 20th century both particles and fields were considered to be real and were considered to be appropriate for the description of very different things.

8. The observability of Compte and Bohr

From Galileo, Bacon and Newton the metaphysics of the experimental definition of reality continued to grow literally without bound until in the beginning of the 19th century Compte codified it into the philosophy of **positivism** in which the only things that are entitled to the status of *reality* are those which can be positively measured. One description of this philosophy is [14]:

"Positivism means the definite abandonment of all search for ultimate causes, and the turning of human attention rather to the laws of phenomena as the only kind of knowledge which is both attainable and useful. Knowledge is of value to us because it helps us modify the conditions in the physical and social world; to do this we need to know how things act, and that is all we need to know."

Metaphysics has been so far degraded by the time of Compte that the term "metaphysical" is used as a pejorative to describe one of the former eras of primitive thought from which we have now happily emerged into the light of pure reason. Science to Compte is the correlation of phenomenological observations between complex systems. His greatest achievement was to apply this vision of science to the most complex system he could think of– Society itself– and is credited with being the father of sociology. Soon thereafter Marx took the identical conception of science as the abstracting of laws made from the observation of complex systems and applied it to economics which lead to the creation of what has since been called "Scientific Marxism."

The ultimate expression of this evolution in the definition of reality by means of experimental observation is the invention and interpretation of quantum mechanics at the hands of Bohr and the Copenhagen school. Thus by the 1920's reality and being are defined in terms of **observable.** The very word defines the metaphysics to be used. The triumph of quantum mechanics in explaining atomic spectra and the success of the uncertainly principle were seen by the 1930's to be a complete vindication of the doctrine that only the observed can be called real. Indeed we teach this in our quantum mechanics courses every day of the week.

9. The revolution of 1964

By the end of the 1930's it is fair to say that absolutely no physicist wanted to challenge this observationally and experimentally based conception of reality. After all it had explained so much which had been thought to be incomprehensible before. Yet there was one nagging problem. When you applied the rules to some questions you sometimes got infinite answers.

The resolution of this problem with infinities was given in 1948 by Feynman, Schwinger and Tomonaga. We can now interpret their procedure as a breakdown of the metaphysical premise that only the observed is real but it was certainly not viewed as such at the time. It was merely a useful device for getting rid of a nagging problem. But because it is in fact the precursor to a much bigger shift in point of view it is most helpful to present this invention of renormalized quantum field theory from a metaphysical rather than from a computational perspective.

Reality in 1948 consisted in several metaphysical assumptions:

1) Space is continuous and, even more strongly, all physically observed properties had to obey the Einstein laws of special relativity;

2) Particles are observable in accelerator experiments and are in a close (usually one to one) correspondence with fields. Fields and particles were considered to be interchangeable from the point of view of "reality".

3) From these fields there was constructed a dynamical principle which allowed mathematical calculations to be done. These interactions were considered to be local in that the fields depended on a single space-time point and only products of fields at the same space-time point were allowed.

It was calculations coming from these three principles that sometimes gave infinite results.

In effect, though this is not how it was viewed at the time, Schwinger, Feynman and Tomanaga, modified the metaphysics of this situation by replacing the first metaphysical principle and the easiest explanation of their replacement (though this is not technically what they did) is to replace continuous space with a lattice with a spacing a. Then all computations were carried out on this fictitious conception of space. However, it was realized that the scale of laboratory observations could not possibly be the scale of this fictitious lattice and at the end of the calculation the theory was rescaled to go from the scale of the lattice to the scale of the laboratory and then a limit was taken that made the lattice spacing go to zero in relation to the laboratory length scale which was kept finite. This process of **changing the normalization of the length scale is called renormalization**

This procedure gave finite answers where before there were infinities and is one of the greatest triumphs of 20th century physics.

This procedure will also be recognized as precisely the idea of the incommensurability of the metaphysical and the observed length scale introduced by Aquinas in 1255.

Of course this interpretation of the theory renormalization of quantum electrodynamics as the reinvention of one of the key parts of the metaphysics of Aquinas was not made in 1948. And moreover the invention of renormalization had only destroyed one of the metaphysical principles of quantum field theory of 1948. But even renormalization theory retained the more or less direct connection between particles and fields. As very important examples I need only point out the famous 1954 paper of Yang and Mills [15] on non Abelian gauge theory where the proton and neutron are each represented by their own field and the equally famous paper of Lee and Yang [16] of 1956 where parity violation in weak interactions are explained by a theory which again has a one to one correspondence between fields and particles.

But this one–to–one correspondence of particles with fields was not to last for long and the first suggestion that it contains contradictions and paradoxes was made by Schwinger [17] in the preface to his book *Selected Papers in Quantum Electrodynamics;*

"Thus, although the starting point of the theory is the independent assignment of properties to the [electromagnetic and electron] fields, they can never be disengaged to give those

properties observational significance. It seems that we have reached the limits of the quantum theory of measurement, which asserts the possibility of instantaneous observations, without reference to specific agencies. The localization of charge with indefinite precision requires for its realization a coupling with the electromagnetic field that can attain arbitrarily large magnitudes. The resulting appearance of divergences, and contradiction, serves to deny the basic measurement hypothesis. We conclude that a convergent theory cannot be formulated consistently within the framework of present space–time concepts." This is a direct and explicitly stated challenge to the Baconian metaphysics of observability. Furthermore Schwinger went on to illustrate his philosophical idea by inventing a model in one space and one time dimension [18] where an electromagnetic field and a massless electron field do indeed merge to yield one single massive excitation.

But the full attack on the one–to–one correspondence in made in 1964 by Murray Gell–Mann [19] in the paper "A schematic model of baryons and mesons" where the spectrum of strongly interacting particles is explained by introducing the notion of a quark.

I have now arrived at the dangerous part of my talk. As long as I have talked about people who are either dead or whose papers have clear and incontestable correct statements I am on fairly safe ground. But with the paper of Gell-Mann I am dealing with someone very much alive. As to clarity I will quote the author himself and let the reader judge.

Gell-Mann wanted to explain why the strongly interacting baryons and mesons have masses which are related by a group theoretic symmetry. For our consideration the mathematics of the symmetry is not important. What is important is that the observed particles were not the simplest way to realize the symmetry and that the simplest explanation of the masses of the observed strongly interacting particles was obtained in terms of three hypothetical objects which he called "quarks" after a reference he quotes from *Finnegans Wake* by James Joyce. These hypothetical objects have fractional charges of $-\frac{1}{3}e$ and $+\frac{2}{3}e$. He then writes the following 2 sentences in the last paragraph:

"It is fun to speculate about the way quarks would behave if they were physical particles of finite mass (instead of purely mathematical entities as they would be in the limit of infinite mass)"

"A search for stable quarks of charge $-\frac{1}{3}$ *or* $+\frac{2}{3}$ *and/or stable di-quarks of charge* $-\frac{2}{3}$ *or* $+\frac{1}{3}$ *or* $+\frac{4}{3}$ *at the highest energy accelerators would help to reassure us of the non-existence of real quarks."*

If Aquinas felt that he had to devote an entire paper to an explanation of a few lines of Boethius it is not out of place to try to find out what Gell-Mann was talking about.

To begin with it is clear that he uses the most profound and debated words of metaphysics; **non-existence** and **real** and makes the extremely metaphysical distinction of **physical particles** as opposed to **hypothetical mathematical objects.** It is equally clear that he never defines what he means by these words.

One not implausible inference is that Gell-Mann was on the horns of a dilemma.

The dilemma is as follows. The theory as proposed by Gell-Mann is based on fields called quarks, but at the time of the proposal in 1964 no particle had ever been found that corresponded to the field. Gell-Mann on the one hand wanted to follow Baconian metaphysics and assert that quarks were real if they could be observed in high energy accelerator experiments. On the other hand he clearly seems to be worried that they would not be detected in these experiments.

In fact particles which would correspond to these quark fields have never been found. But nevertheless Gell-Mann's suggestion of quark fields was not rejected. Instead a truly amazing thing happened. Physicists abandoned the second of the 1948 metaphysical principal and accepted the idea that

Fields and particles, not only are not in one to one correspondence but are completely different concepts.

In particular:

1) Fields are considered to be fundamental and the observed particles are considered to be complex excitations of these fields;

2) Protons, neutrons, pi mesons and other strongly interacting particles are indeed observed as particles but there are no such thing as proton, neutron or pi meson fields;

3) Quark fields are considered as real even though there is no such thing as an observed quark particle. This phenomena of a field with no corresponding particle is referred to as **confinement.**

But this concept of a field with no material particle to go with it is exactly the concept of the **immaterial substance as discussed by Aquinas in 1255.**

This point of view was so rapidly adopted that by 1974 in the paper "Confinement of quarks" Ken Wilson [20] writes *"The success of the quark-constituent picture both for resonances and for deep-inelastic electron and neutrino processes makes it difficult to believe quarks do not exist. The problem is that quarks have not been seen. This suggests that quarks, for some reason, cannot appear as separate particles in a final state."* He then goes on to credit Schwinger [18] with exhibiting a confinement mechanism in 1962 and then proposed his own mechanism based upon a lattice realization of space on the metaphysical scale. Thus from 1948 to no later that 1974 physics abandoned the metaphysics of that reality is observation which had ruled scientific thought since 1610.

10. The rise of the new metaphysics

The new metaphysical age which physicists have entered since 1964 is immeasurably richer and productive than the metaphysics abandoned in 1610. We have indeed returned to the kinematic notions which Aquinas had of the incommensurate length scales and the immaterial substance but we now also have quantum dynamical principles from which calculations can be made.

But even more than that has occurred. The very balance between experimental and theoretical thought has been profoundly altered in the past 30 years. It is no longer true that theorists wait hungrily for data and pounce on every bump in a cross section measurement. And while it remains as true as ever that new experiments can give as great a revelation as the discovery of the moons of Jupiter it is no longer the case that the discovery of a new comet or asteroid sets off a wave of theoretical computations.

The new metaphysics has made it respectable to once again ask a purely theoretical question. Or to put it in another fashion, theorists now cannot escape the fact that over the decades and centuries there have piled up an enormous number of observed phenomena which we do not have a really good theoretical explanation for. Once the metaphysics which is dominated by experiment is abandoned it is no longer acceptable for theorists to hide behind the claim of insufficient experimental data when they have failed to construct an adequate theory. It is no longer acceptable to conclude a theoretical paper by pushing the mass of some new presumed particle up higher than the current limit of observation and then calling upon people to build a bigger accelerator to test the conjecture. Theoreticians are being forced to answer theoretical questions in theoretical terms.

Let me give an example of a purely theoretical question for which there can be no experimental answer. We all know that quantum mechanics is invented to make atoms stable and that Fermi statistics are needed to make bulk matter exist. This was mathematically proven in the late 60's. But it is a slight scandal that we have no proof yet that organic chemistry exists. By this I mean the following. The physics which governs organic chemistry is believed to be the non relativistic quantum mechanics of atomic nuclei (treated as points) and electrons interacting with the coulomb interaction. This interaction is invariant under parity. But all large organic molecules like DNA are twisted and maximally violate parity conservation. How does this happen?

To be more precise we note that a key feature of experimental reality it that the mass ratio of the proton to the electron is 1836:1. It is plausible that this large mass ratio can

be used to make valid the ball and stick models of organic molecules which are commonly used to illustrate the twisting of DNA. But surely if the mass ratio is 1:1 then organic chemistry as we know it is impossible. So my purely theoretical question is this; how large does the mass ratio have to be before organic chemistry happens? This is an explicit theoretical question which cannot be answered by experiment.

Moreover, once you abandon the pre 1948 metaphysics and accept infinite length scales and immaterial substances there is no reason to keep any of the old metaphysics at all. In particular there is absolutely no longer any reason to limit yourself to the belief that fields interact only at points because after all these fields are in the metaphysical space and as Aquinas emphasized our notions taken from the world of observation need not be valid on the length scale of the fundamental metaphysical objects. Therefore in the last 25 years we have invented string theory which abandons the principle of point like interactions of fields and replaces the concept of the fundamental point with that of the fundamental string. In other words the fundamental objects of reality are extended instead of point like.

Indeed there is not even any reason to suppose that the metaphysical space has the same number of dimensions as observed space and it is now perfectly acceptable to talk of metaphysical spaces of 10, 11, or 26 dimensions just so long as they all give an observed spacetime of 4 dimensions.

In order to put string theory in perspective I turn once again to a book of Galileo. This time his famous book *The Dialogue Concerning the Two World Systems* [21] published in 1632. This book presented the difference between the view of Ptolemy, that the earth did not move, and the view of Copernicus that the earth moved around the sun. At the time both of these views could easily be called different metaphysics. Both lead to predictions and explanations of the observed data.

Galileo set out to apply this new point of view of Copernicus to as much observational reality as he could find. But he found that a challenge to an accepted scientific point of view is rough going. He was charged with heresy, hauled before the Roman inquisition, tried and convicted of having the wrong views. This trial is justly famous and we now recognize that even though condemned he was correct. But what is often forgotten is that at the time in 1632 **Ptolemy's theory fit the data better that Copernicus' did.** Moreover, some of Galileo's arguments such as the statement that the moon had nothing to do with the tides are just flatly wrong. In 1632 it was not clear which world view was correct.

The same can be said about string theory today. The conventional standard model of quantum field theory based on the immaterial objects of quarks and gluons and using the dynamical principle of the Yang -Mills interaction fits all the observed data. Moreover it is quite possible that there are many mistakes in our understanding of how to get observable predictions from the metaphysical strings. Just as Galileo needed to abandon his assumption of circular orbits before he could get better agreement with the data that the Ptolemaic theory would give, so string theorists surely need better computational tools to make predictions that can give decisive tests between the two world views. At present it is not established which world order on the metaphysical level better describes observable reality.

The relation between experimental physics, mathematics and metaphysics is now very usefully described by the classification given by Aquinas in 1255. Experimental physics studies observed properties and the relations between them. Metaphysics posits the world of ultimate unchanging reality and mathematics is the connection between the two. If the application of mathematics to the metaphysical does not yield observation then we must change the metaphysics. We may never attain complete knowledge of the metaphysical world but we can and do improve our comprehension of it.

The new metaphysics of Aquinas thus puts a much greater emphasis on mathematics that did the metaphysics of Bacon. In the last 30 years the needs of making the connection between the metaphysical and the observed has required the invention of much new mathematics. This new mathematics turns out to be deeply related to both statistical mechanics on the one hand and to topological and algebraic problems in mathematics on the other. It is the mathematical progress that came from this new physical viewpoint for which Witten was awarded the Fields Medal in 1990. These advances would not have been possible had experimental data been allowed to continue to be the sole arbiter of our theoretical thought.

11. Conclusion

I have now concluded my journey through the history of physics, mathematics and metaphysics. I hope I have made it clear that the easiest and clearest way to understand both the history and present day developments in the theoretical sciences is not to focus on the details of observational experiments or to focus on the details of mathematical computation but to focus on the metaphysical conception of reality which is being used.

Because whether or not we are willing to admit it in so many words all scientific research is completely determined by the metaphysical principle of the person doing the research. Each one of us has his/her own metaphysical conception of reality which guides our actions. Each of us profoundly believes in his/her own metaphysics. But no two of us have exactly the same metaphysics in common.

Indeed while the details of experiments and mathematical computations will forever be the province of those few who choose to specialize in them the metaphysics of science is comprehensible to everyone. Indeed metaphysics is not the property of scientists alone but in truth each and every person under the sun has their own unique set of metaphysical beliefs. These are the questions which people have thought about from the beginning of time. Metaphysics, in its own individual way, is a universal language.

But if it is true that physics has dealt with questions of great popular interest for 2500 years then why do we lament for the lack of jobs and lack of federal support? Why do so many people seem hostile to science?

This question is also not a new one. And thus I will close by again quoting Francis Bacon [22] from 1620:

Moreover, even if such hostility were to cease, the growth of the sciences would still be hindered by the fact that effort and hard work in that direction go unrewarded. For those cultivating the sciences and those paying for them are not the same people. For scientific advances come from great minds, whereas prizes and rewards of science for this knowledge are in the hands of the common people, or leading citizens, who only occasionally are even moderately educated. Advances of this kind not only go unrewarded with prizes and substantial benefits, but do not even enjoy popular esteem. For they are beyond the grasp of most people, and are easily overwhelmed and extinguished by the winds of common opinion. It is no wonder if such an enterprise which is not honored does not prosper.

And he should know about politics better that almost any scientist in history because he was not only a great philosopher but was also the Lord High Chancellor of England.

Acknowledgments

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